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Impact of a Municipal Wastewater Effluent on Water Quality, Periphyton, and Invertebrates in the Little Miami River Near Xenia, Ohio[1]

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ABSTRACT. Water quality, periphyton, and invertebrates were determined for the Little Miami River above and below a municipal wastewater outfall during July-September 1984. The primary impact of the effluent on water quality was to increase nitrogen-containing compounds. Organosphosphate and chlorinated insecticides were non-detectable in any water sample and levels of potentially toxic metals were low. A total of 122 attached periphyton species were identified from substrates colonized for four weeks during each month. Diatoms dominated the periphyton and were represented by 106 species. The more abundant forms were *Amphora perpusilla* and *Navicula minima* which comprised on the average over 70% of the total cell volume. Thirty-one algal species of minor abundance were observed only above the discharge point, relative to eight restricted below the discharge in water containing approximately 15–35% effluent. *A. perpusilla* comprised on the average 80% of all forms below the outfall relative to 30% above during August and September. In contrast, *N. minima* was more abundant above (39%) than below (2%). Despite these differences in composition, a diversity index was relatively high, ranging from 1.7 to 3.2. In addition, algal density above and below the outfall was similar. At least 20 species of invertebrates, primarily chironomids, were identified during the study. Sixteen invertebrates occurred above the discharge point and 12 below.

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INTRODUCTION

The reported descriptions of the biota in Ohio's streams are not abundant but are more numerous than those detailing communities occurring above and below municipal wastewater outfalls. More studies such as that by Lowe and McCullough (1974), which described the effect of effluent on the diatoms in the North Branch of the Portage River are needed for Ohio's waters receiving effluent discharges. The U.S. EPA's (1985) recently formulated water quality based policy recommends the evaluation of the aquatic safety of municipal effluents to maintain the designated use of the corresponding receiving water. This analysis, which may be needed prior to obtaining or renewing a National Pollutant Discharge Elimination System (NPDES) permit, includes biomonitoring of the receiving water.

The Little Miami River is a National Scenic River that has been designated by the Ohio EPA as an exceptional warm-water habitat (Ohio EPA 1985). This classification includes water of exceptional chemical quality, capable of supporting diverse aquatic communities and having outstanding recreational fisheries. The algal community for this river (Weber and Moore 1967; Weber and McFarland 1981), water quality, fish, and macroinvertebrate communities (Wynes and Wissing 1981) have been described for selected areas. However, the effects of treated wastewater effluent on localized periphyton and invertebrate assemblages in the upper reaches of this river have not been detailed. This paper summarizes a summer study that investigated the impact of municipal wastewater on water quality, periphyton, and invertebrates in the Little Miami River.

METHODS AND MATERIALS

STUDY AREA. The study area was located on the Little Miami River near Xenia, Ohio (Fig. 1). This river begins in Clark Co. near South Charleston, Ohio and flows 170 km to its confluence with the Ohio River (Weber and Moore 1967). Stream discharge at the study area during the study ranged from 5.1 to 28.8 m^3s^{-1} (USGS 1984). The investigation was conducted in the river above and below the Xenia Ford Road Sewage Plant outfall. This treatment facility provides secondary treatment for an influent comprised primarily of municipal sewage. Approximately 2.5 MGD of treated effluent are discharged to the river.

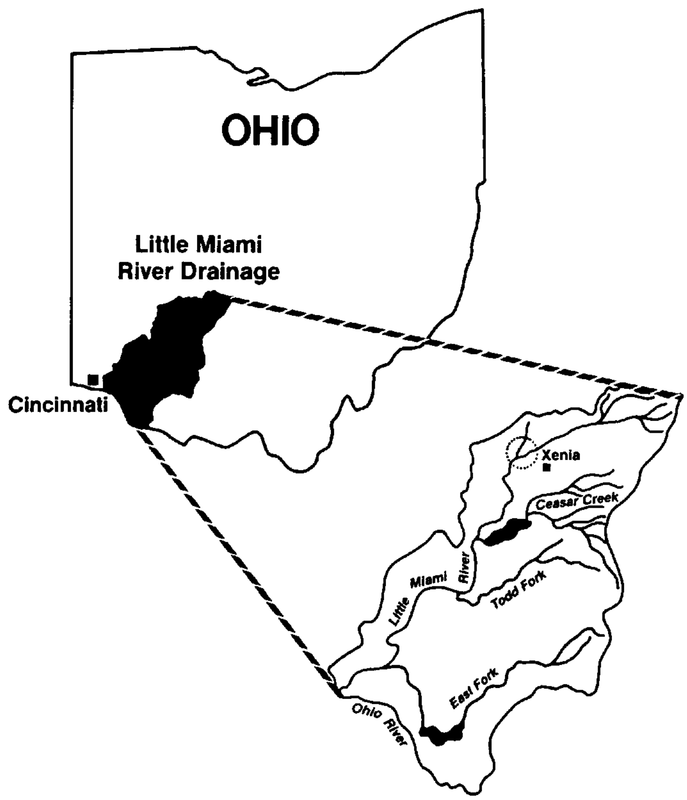

FIGURE 1. The Little Miami River drainage basin showing the study area near Xenia, Ohio (Greene Co.).

PROCEDURE. Periphyton were colonized for four weeks during each of the following months; July, August, and September, 1984 on plexiglass plates (108 cm^2) suspended vertically in the two river areas. The first collection site was relatively free of contaminants and located approximately 100 m above the outfall. Periphyton were also colo-

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nized 250 m below the outfall in water containing 15%–35% effluent, based on two dye tracer studies conducted during July and September.

At least eight slides of periphyton from each of the two river areas were sampled monthly for community analysis and chlorophyll *a*. The periphyton were preserved in gluteraldehyde (25% in water) prior to identification. The volume of solution was measured and samples split into separate subsamples for the analysis of diatoms and non-diatoms. The non-diatom algae were placed in a Palmer-Maloney nannoplankton counting chamber for identification (Palmer and Maloney 1954). Confirmation of genus and species were by examination under oil immersion (total magnification = 1000×) using the keys of Bourrelly (1966, 1968, 1970), Drouet (1968, 1973, 1978, 1981), Drouet and Daily (1956), and Hustedt (1930). Chlorophyll *a* content was measured spectrophotometrically using the trichromatic equations described in Lind (1979).

Diatoms were cleaned of organic material by nitric acid digestion, dripped on coverslips and mounted on glass slides. Identification was to species level, and the cells enumerated (500 counts) using a total magnification of approximately 1100×. Diatom cell densities were determined by species proportional counts based on the original total periphyton cell counts (including diatoms) in the Palmer-Maloney chamber using *Standard Methods* (APHA 1975). Identifications were made following Patrick and Reimer (1966, 1975). Because of the separation of chloroplasts from the very abundant small diatoms, it was difficult in many cases to differentiate small coccoid forms. For this reason, an underestimation of undetermined coccoid Chlorophyta and undetermined microflagellates may have occurred. A collection of the periphyton is maintained at the Philadelphia Academy of Natural Sciences.

Invertebrates were colonized for four weeks on circular Hester-Dendy plates (48 cm^2) suspended in above and below outfall river areas. Invertebrates were preserved in 80% ethanol until identification. The samples were sorted into morphological groups, and the chironomids were mounted by collapsing the head in Hoyer's solution. Additional identifications, especially for the chironomids, were made using the head and mouth parts as diagnostic characters. The invertebrates were identified using the systematics described by Pennak (1975) and Wiederholm (1983).

SIMILARITY AND DIVERSITY INDICES. Two indices of community similarity were determined for the algal samples. Values for these indices range from 0 to 1 with the highest degree of similarity being represented by 1. The coefficient of community (*CC*), (Jaccard 1901), was calculated as follows:

$$CC = \frac{\text{species common to both samples}}{\text{total number of species in both samples}} \quad (1)$$

The second index, *C*-lambda, (Morosita 1959) measured the degree of similarity between the periphyton samples in species richness and evenness and was determined as:

$$C\lambda = \frac{2\sum_{i=1}^{S} x_i \cdot y_i}{(\lambda X + \lambda Y)x.y.}$$

where: S = number of species encountered
x_i = the number of individuals of species i in sample X
$x. = \sum x_i$
$\lambda X = \sum[x_i(x_i - 1)]/[x.(x. - 1)]$
y_i, $y.$ and λY are defined analogously for sample Y

A diversity index (Shannon and Weiner 1963) was calculated as follows:

$$H' = -\sum_{i=1}^{S} \frac{M_i}{V} \log_2 \frac{M_i}{V}$$

where: S = number of species observed in the count
M_i = frequency of the ith species
V = total number of species counted

WATER QUALITY. The chemical quality of the effluent, and river water above and below the outfall was determined at least twice monthly and, more often, weekly. In addition, concentrations of BOD and suspended solids in effluent were determined daily by the treatment plant personnel. The grab samples of effluent and river water were analyzed for dissolved oxygen, conductivity, temperature, and pH using an automated analyzer. Hardness, alkalinity, chlorine, nitrogen containing compounds, and phosphorus were determined using standard methods (APHA 1975). Metals were analyzed using inductively coupled plasma-atomic emission spectrophotometry and a graphite furnace (U.S. EPA 1979). Organophosphates and chlorinated insecticides were determined following FDA guidelines (FDA 1971).

RESULTS

WATER CHEMISTRY. The more noticeable differences in the river below the outfall were increases in conductivity, chlorine, and nitrogen-containing compounds (Table 1). For example, ammonia-nitrogen above the outfall averaged 0.01 (mg/l) relative to 1.7 mg/l downstream below the mixing zone (100 m below the outfall). Nitrate-nitrogen increased from 0.8 mg/l to 6.6 mg/l in the mixing zone, and 1.8 mg/l after complete mixing. Other parameters such as orthophosphate, water temperature, total hardness and alkalinity were only slightly elevated below the outfall. No chlorinated insecticides or organophosphate compounds were detected in any of the effluent and water samples. Metal concentrations in the river below the discharge point were similar to those above with only slight elevations in cadmium and copper. Mercury concentrations in all cases were below the detection limit of 0.0004 mg/l. Water quality parameters for metals and pesticides were below the corresponding Ohio numerical and narrative criteria for aquatic life (Ohio EPA 1985). However, ammonia concentrations exceeded at times the recommended limits by 30%.

PERIPHYTON. A total of 122 species of periphyton (29 genera) were identified during the study (Tables 2 and 3). One hundred and six of these species were diatoms of which pennate forms predominated especially *Navicula* which was represented by 41 species. Eighty-three species were common to both the upstream and downstream waters. Thirty-one taxa were identified only above the outfall and included species of *Synedra, Coelastrum, Spirogyra,* and *Cryptomonas*. Eight species mostly diatoms were collected only below the discharge point.

The pennate diatoms, *Amphora perpusilla* and *Navicula minima* were the more abundant species averaging over 70% of the periphyton regardless of the collection site (Fig. 2). *A. perpusilla* dominated the periphyton below the outfall in August and September where it comprised over 80% of the total cell volume relative to an average of 30% above during the same months. In contrast, this species was more abundant in the upstream area during July. *N. minima* was more numerous in the upstream areas during August and September. For example, during August, it averaged 39% of the periphyton colonized above the outfall relative to 2% in below outfall river water. The abundance of this species in July was comparable regardless of the collection site. Species of lesser abundance identified during the study include *Nitzschia amphibia* (% of cell volume = 2-4%), *Achnanthes lanceolata* (1-9%), *Achnanthes minitussima* (2-6%), and *Cocconeis placentula* (0-8%).

The similarity of the periphyton collected from the two river areas as measured by the similarity indices varied (Table 4). The *C*-lambda values ranged from 0.71 to 0.86 indicating a relatively high degree of similarity, whereas the *CC* values were considerably less ranging from 0.39 to 0.40. The *C*-lambda index, unlike the

TABLE 1

Water quality of the Little Miami River above and below the Xenia, Ohio, municipal sewage outfall. Values represent the mean and range ( ) of at least 15 measurements taken during May-October, 1984. Values for metals and organics are in mg/l.

	Above outfall	Effluent	Below outfall
Temperature (°C)	17.5 (5.3-23.0)	19.1 (16.1-26.0)	18.5 (13.8-22)
Conductivity (umhos)	715 (560-850)	1300 (1150-1500)	840 (700-960)
pH (units)	6.8-8.5	7.2-8.3	6.8-8.4
Total Hardness (mg/l)*	281 (210-400)	316 (240-440)	291 (220-350)
Ammonia-Nitrogen (mg/l)	0.01 (0-.04)	8.3 (.5-18.4)	1.7 (0-4.0)
Nitrite-Nitrogen (mg/l)	0.07 (0-.2)	0.92 (.05-2.98)	0.39 (.01-3.4)
Nitrate-Nitrogen (mg/l)	0.8 (.1-4.0)	13.3 (.2-54.0)	6.5 (.95-24.0)
Orthophosphate (mg/l)	0.24 (0-.40)	1.5 (.2-8.0)	0.35 (.1-1.7)
Residual Chlorine (mg/l)	0	0.28 (.1-.5)	0.16 (.01-.30)
Total Alkalinity (mg/l)*	292 (270-318)	372 (338-402)	312 (274-362)
Dissolved Oxygen (mg/l)	8.4 (7.2-14.1)	6.8 (2.5-9.6)	9.4 (7.5-12.3)
Suspended Solids (mg/l)	ND**	6.4 (1-20)	ND
5d BOD (mg/l)	ND	8.1 (3-19)	ND
B	0.009 (.005)	0.16 (.02)	0.013 (.007)
Cd	0.003 (.001)	0.002 (.001)	0.005 (.004)
Cu	0.004 (.002)	0.005 (.003)	0.007 (.009)
Fe	1.00 (.45)	0.08 (.02)	0.93 (.96)
Mn	0.05 (.01)	0.03 (.007)	0.041 (.015)
Ni	0.009 (.0009)	0.02 (.03)	0.009 (.002)
Pb	<.015 —	<.015 —	<.015 —
Zn	0.02 (.003)	0.03 (.006)	0.02 (.005)
Hg	<.0004	<.0004	<.0004
As	<.001	<.001	<.001
Ag	<.001	<.001	<.001
Toxaphene	<.001	<.001	<.001
Vapona	<.0005	<.0005	<.0005
Thimet	<.0005	<.0005	<.0005
Diazinon	<.0005	<.0005	<.0005
Methyl Parathion	<.0005	<.0005	<.0005
Ronnel	<.0005	<.0005	<.0005
Malathion	<.0005	<.0005	<.0005
Parathion	<.0005	<.0005	<.0005
DDE	<.0005	<.0005	<.0005
DDD	<.0005	<.0005	<.0005
DDT	<.0005	<.0005	<.0005
PCB	<.0001	<.0001	<.0001
Dieldrin	<.0001	<.0001	<.0001
Alpha-BHC	<.0001	<.0001	<.0001
Delta BHC	<.0001	<.0001	<.0001
Beta-BHC	<.0001	<.0001	<.0001
HCB	<.0001	<.0001	<.0001
Endrin	<.0001	<.0001	<.0001
Mirex	<.001	<.001	<.001
Methoxychlor	<.001	<.001	<.001

*as mg/l $CaCO_3$
**ND=not determined

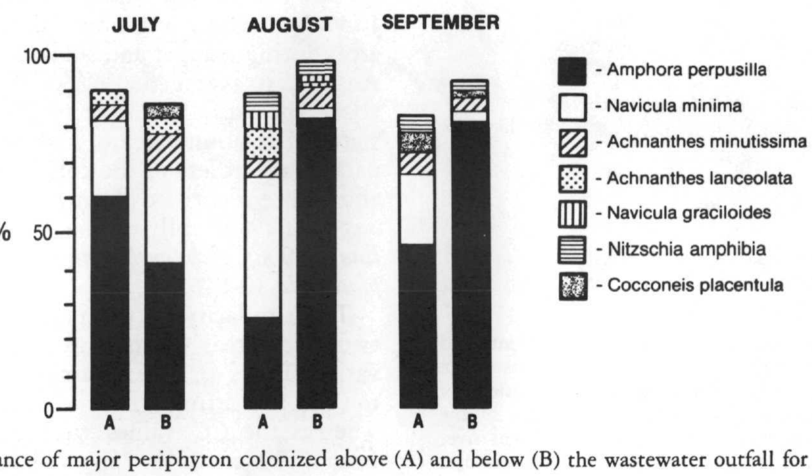

FIGURE 2. Relative abundance of major periphyton colonized above (A) and below (B) the wastewater outfall for 28 days during each month.

TABLE 2

Periphyton species identified in the Little Miami River above and below the sewage outfall.

Species
CHRYSOPHYTA
Achnanthes clevei Grun.
Achnanthes conspicua Mayer
Achnanthes exigua Grun.
Achnanthes hungarica Grun.
Achnanthes lanceolata (Breb) Grun.
Achnanthes lanceolata v. *dubia*
Achnanthes minutissima Kutz.
Achnanthes pinnata Hust.
Amphora ovalis Kutz.
Amphora perpusilla Grun.
Amphora submontana Hust.
Amphora veneta Kutz.
Caloneis bacillum Grun.
Cocconeis pediculus Ehr.
Cocconeis placentula v. *euglypta* (Ehr) Cl
Cyclotella meneghiniana
Cymatopleura solea Breb.
Cymbella affinis Kutz.
Cymbella prostata (Berk) Grun.
Cymbella sinuata Greg.
Cymbella sinuata fo *antiqua* (Grun) Reim.
Cymbella tumida (Breb) VH
Fragilaria pinnata Ehr
Gomphonema abbreviatum (Ag) Kutz.
Gomphonema clevei Fricke
Gomphonema grunowii Patr.
Gomphonema olivaceum (Lyngb.) Kutz.
Gomphonema parvulum Kutz.
Melosira varians Ag.
Navicula accomoda Hust.
Navicula atomus (Kutz) Grun.
Navicula biconica (Patr.)
Navicula capitata Ehr.
Navicula cincta v. *rostrata* Reim.
Navicula cryptocephala v. *veneta* Kutz.
Navicula graciloides A. Meyer
Navicula ingenua Hust.
Navicula luzonensis Hust.
Navicula menisculus
Navicula minima Grun.
Navicula ochridana
Navicula pelliculosa (Breb) Hilse
Navicula peregrina (Ehr) Kutz.
Navicula pupula Kutz.
Navicula pupula v. *mutata* (Krasske) Hust.
Navicula pygmaea Kutz.
Navicula rhynchocephala v. *germainii*
Navicula salinarum v. *intermedia* (Grun) Cl
Navicula secreta v. *apiculata* Patr.
Navicula seminulum Grun.
Navicula subhamulata Grun.
Navicula symmetrica Patr.
Navicula tantula Hust.
Navicula tenera Hust.
Navicula tripunctata (O.F. Mull.)
Navicula tripunctata v. *schizonemoides* (VH) Patr.
Navicula viridula Kutz.
Navicula simplex Krasske
Nitzschia amphibia Grun.
Nitzschia angustata
Nitzschia capitellata
Nitzschia dissipata (Kuetz.) Grun.
Nitzschia dissipata v. *media* (Hantz) Grun.
Nitzschia frustulum (Kuetz) Grun.
Nitzschia frustulum v. *perminuta* Grun.
Nitzschia frustulum v. *subsalina* Hust.
Nitzschia hungarica
Nitzschia keutzingiana Hilse
Nitzschia palea
Nitzschia recta Grun.
Nitzschia sociabilis
Rhoicosphenia curvata (Kutz) Grun.
Surirella minuta
CYANOPHYTA
Schizothrix calcicola (Ag) Gomont
Schizothrix friesii
CHLOROPHYTA
Ankistrodesmus falcatus (Corda) Ralfs
Cladophora glomerata (L) Kutz.
Oedogonium sp.
Scenedesmus acuminatus (L) Chodat
Scenedesmus quadricauda (Turpin) Breb.
Scenedesmus sp.
Stigeoclonium lubricum Kutz.
EUGLENOPHYTA
Trachleomonas sp.

coefficient of community, incorporates the consideration of abundance and therefore is likely the more valid measure of similarity. The diversity index ($\overline{d}$) was relatively high ranging overall from 1.7 to 3.2 with slightly greater values for the periphyton colonized above the waste discharge. The trend in algae density was variable. Density of the above outfall periphyton was greater than that for the below assemblage in July but less in August. For example, periphyton density during August averaged 2018 cells/mm^2 (above) and 4765 cells/mm^2 (below). Periphyton densities for the two collection sites during September were comparable. Lastly, the chlorophyll *a* concentrations for the downstream algae were slightly, but not significantly, greater ($P < 0.05$) during July and September.

INVERTEBRATES. The numbers of invertebrates colonized were low, and the data are therefore restricted to reporting only their presence or absence at the two sampling locations. Thus, their use in this study is limited. Overall, at least 20 species of invertebrates were identified (Table 5). Fourteen of these were dipterans with the chironomids being the most numerous. Species of Empidae, Naididae, Nematoda, and Tipulidae were found only above the outfall. Three of the four species collected only below the discharge point were chironomids, and the other was an aquatic beetle. Eight invertebrates were common to both river areas.

DISCUSSION

The treated wastewater effluent after dilution had a measurable effect on the Little Miami River periphyton by primarily altering composition. Several of the identified algal species indicate organic pollution (index range = 17–19), based on Palmer's (1969) genus and species pollution indices. Species considered indicative of organic contamination were identified below and, to a lesser extent, above the discharge point and included *Ankistrodesmus falcatus, Cyclotella meneghiana, Nitzschia palea, Synedra ulna,* and *Scenedesmus quadricauda* (Palmer 1962). These forms were of minor abundance, however, and the environmental relevance of the species indicator concept in this study is questionable. The sensitivities of the major algal species observed in this study have not been reported. It appears, however, that *A.*

TABLE 3

Periphyton identified only in the Little Miami River above and below the sewage outfall.

Species above	Species below
CHRYSOPHYTA	CHRYSOPHYTA
Achnanthes biporoma (Hohn & Hellerm.)	*Achnanthes linearis* f. *curta* H. L. Smith
Achnanthes linearis v. *pusilla* Grun.	*Gomphonema intricatum*
Amphora ovalis v. *pediculus* Kutz	*Gyrosigma scalproides*
Cocconeis placentula v. *lineata* (Ehr.) V.H.	*Navicula canalis* Ehr.
Cymbella minuta Hilse ex. Rabh.	*Navicula grimmei* Krasske
Diatoma vulgare Bory	*Navicula sicula* v. *migrans*
Gomphonema subclavatum Grun.	
Navicula gregaria Donk	CHLOROPHYTA
Navicula indifferens Hust.	*Cosmarium* sp.
Navicula lanceolata f. *minuta* Rabh.	
Navicula mutica Kutz.	PYRRHOPHYTA
Navicula paucivisitata Patr	*Peridinium* sp.
Navicula subatomoides	
Navicula viridula v. *linearis* Hust	
Navicula viridula v. *rostellata* Kutz	
Navicula sicula v. *migrans* (Ehr.)	
Nitzschia fonticola	
Nitzschia gracilis	
Nitzschia sinuata (Thwaites) Grun.	
Nitzschia sinuata v. *tabelliaria* Grun.	
Nitzschia tryblionella v. *debilis*	
Surirella angusta Kutz	
Synedra parasitica (W. Sm.) Hust.	
Synedra parasitica v. *subconstricta* (Grun.) Hust.	
Synedra ulna (Nitzsch) Ehr.	
Synedra ulna danica (Kutz.) V. H.	
Synedra ulna v. *oxyrhynchus*	
CHLOROPHYTA	
Coelastrum sp.	
Scenedesmus ecornis (Ralfs) Chodat	
Spirogyra sp.	
CRYPTOMONAD	
Cryptomonas sp.	

TABLE 4

Structural characteristics of periphyton collected from the Little Miami River above (A) and below (B) the sewage outfall. Values represent mean and standard deviation.

	Similarity Indices		H'***		Chlorophyll a (mg/cm^2)		Density ($cells/mm^2$)	
	$C\lambda$*	CC**	A	B	A	B	A	B
July	0.82(0.13)	0.39(0.04)	2.5(.2)	2.3(.3)	0.07(.02)	0.10(.02)	2840(130)†	1943(373)
August	0.71(0.23)	0.39(0.07)	2.5(.1)	1.7(.9)†	0.10(.01)	0.10(.01)	2018(924)	4765(847)†
September	0.86(0.07)	0.40(0.11)	3.2(.5)	2.5(.1)	0.08(.01)	0.10(.03)	4300(1076)	3589(1571)

*from Morosita (1959)
**from Jaccard (1901)
***from Shannon-Weiner (1963)
† = significant difference

perpusilla and *A. minutissima* were more tolerant than *N. minima* to the sewage effluent. In addition, the absence of Naididae, Empidae, Tipulidae, and Nematodes below the outfall suggests their sensitivity. However, the concept of indicator species as applied to aquatic invertebrates may be tenuous and has been discouraged due to their wide range of tolerance (Roback 1974).

The magnitude of the effluent impact and its ecological relevance is difficult to judge, based on the available data. The densities of several periphyton were reduced by the effluent, and some algae and invertebrates were not observed below the outfall, relative to above. In contrast, the relatively high diversity and similarity (C-lambda) index values and the lack of gross effects on community structural characteristics, e.g., chlorophyll a, suggest an impact that is not severe. This conclusion is also supported by the finding that effluent from this same source had no significant effect on the fish and macroinvertebrate communities in the river (Wynes and Wissing 1981) which utilize, in part, periphyton as a food resource.

The diatom community in the Little Miami River reported here (106 species) was similar in number to the 111 species identified for the effluent-impacted

TABLE 5

Invertebrate species colonized above and below the municipal sewage outfall during July-September, 1984. A = above outfall; B = below outfall.

NEMATODA	
unidentified species	A
NAIDIDAE	
unidentified species	A
TRICHOPTERA	
Cheumatopsyche sp.	A
Hydroptila sp.	A, B
COLEOPTERA	
Optioservus sp.	A, B
Cyphon sp.	B
DIPTERA	
Tipulidae	
Antocha sp.	A
Empidae	
unidentified species	A
Chironomidae	
Alabesmyia sp.	B
Chironomus sp.	A, B
Corynoneura sp.	B
Cricotopus sp.	A
Dicrotendipes sp.	A, B
Nanocladium sp.	A
Phaenopsectra sp.	A, B
Polypedilum sp.	A, B
Rheotanytarsus sp.	A
Stenochironomus sp.	A, B
Tanytarsus sp.	A, B
Thienemannimyia sp.	B

North Branch of the Portage River (Lowe and McCullough 1974). *Navicula cryptocephala* and *Surirella ovata* predominated in the unpolluted areas of the North Branch whereas *Gomphonema parvulum* was more abundant in the effluent impacted zone. Diatoms common to both studies numbered 42 species; however, 64 taxa reported for the Little Miami River were not observed in the North Branch. Conversely, 65 species identified by Lowe and McCullough (1974) were not observed in the Little Miami River. The largest difference in the composition was for *Navicula*. The reason for this difference could, in part, be due to the fact that the North Branch study was conducted during October to February.

Lastly, the 106 diatoms identified for the Little Miami River near Xenia, Ohio, is similar to the 98 species identified for the river near Cincinnati (Weber and McFarland 1981). In addition, the community composition for the two river areas based on genera was similar with major diatoms in the river near Cincinnati being *Achnanthes minutissima* and *Amphora ovalis*. The total number of diatoms in the Little Miami River near Xenia, relative to those reported for other Ohio streams, is exceeded by the 190 and 166 species respectively, for Cedar Run and Scioto River Basin (Collins and Kalinsky, 1977; Hufford and Collins 1976).

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